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ANALYSIS OF THE EFFECTS OF BODY ARMOR AND LOAD-CARRYING EQUIPMENT ON SOLDIERS' MOVEMENTS

Part III
Gait Analysis

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13. ABSTRACT *(Maximum 200 words)*
This is one of three reports of a study on the effects of armor vests and fighting loads on soldiers' movements. Twelve male soldiers performed seven planar movements and a walking task while wearing the vests and fighting loads with either a T-shirt and shorts or the Temperate Battledress Uniform (BDU). Two measurement methods were applied to quantify the extent of the movements, one of which was a video- and computer-based technique. This report contains results of the analyses of self-paced walking, as quantified using the video technique. Temporal and kinematic variables were measured to compare gait patterns and body postures of the soldiers wearing the BDU alone and in combination with the Personnel Armor System for Ground Troops (PASGT) vest and the All-Purpose Lightweight Individual Carrying Equipment (ALICE) fighting load. It was found that use of the armor vest and the fighting load increased left support and double support stride periods, decreased the range of trunk tilt angle, and increased the range of vertical displacement of the hip. A second report (NATICK/TR-98/002) contains comparisons of the data acquired on the planar movements using the two measurement techniques, and a third report (NATICK/TR-98/003) contains results of the effects of the vest and fighting load designs on the planar movements.

14. SUBJECT TERMS

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PREFACE

The study reported here was conducted under U.S. Army Soldier Systems Command, Natick Research, Development and Engineering Center contract DAAK60-93-D-0005 with GEO-CENTERS, INC., Newton Centre, MA. The work was performed at the Center for Military Biomechanics Research, Natick Research, Development and Engineering Center. Carolyn K. Bensel of the Center was the project officer for the contract. This project is part of the 6.2 program 1L162723AH98AAKOO (Aggregate Code T/B1368) — Biomechanical Approach to Soldier-CIE Integration, which is being carried out by Dr. Bensel and other members of the Center.

This report is one of a series of three. The references for the other reports are:

Woods, R. J., Polcyn, A. F., O'Hearn, B. E., Rosenstein, R. A., and Bensel, C. K. (1997). *Analysis of the effects of body armor and load-carrying equipment on soldiers' movements. Part I: Technique comparisons* (Tech. Rep. NATICK/TR-98/002). Natick, MA: U.S. Army Natick Research, Development and Engineering Center.

Woods, R. J., Polcyn, A. F., O'Hearn, B. E., Rosenstein, R. A., and Bensel, C. K. (1997). *Analysis of the effects of body armor and load-carrying equipment on soldiers' movements. Part II: Armor vest and load-carrying equipment assessment* (Tech. Rep. NATICK/TR-98/003). Natick, MA: U.S. Army Natick Research, Development and Engineering Center.

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ANALYSIS OF THE EFFECTS OF BODY ARMOR AND LOAD-CARRYING EQUIPMENT ON SOLDIERS' MOVEMENTS
Part III: Gait Analysis

Introduction

A major concern in assessing the acceptability of items of protective clothing and equipment for use by soldiers is the extent to which the items may restrict body movements, thereby impeding mission performance. Research sponsored by this laboratory in the 1950s identified tests of gross motor activities that are sensitive to the effects of different clothing ensembles (Saul and Jaffe, 1955) and established the metrics of the tests (Dusek, 1958b; Dusek and Teichner, 1956). These methods have since been applied by this laboratory in a number of studies of military field clothing (Bensel, Bryan, and Mellian, 1977; Bensel, Teixeira, and Kaplan, 1987; Dusek, 1958a; Lockhart and Bensel, 1977), ballistic protective vests (Bensel, Fink, and Mellian, 1980; Bensel and Lockhart, 1975; McGinnis, 1972), and load-carrying equipment (Bensel et al., 1980; Bensel and Lockhart, 1975). The investigations have generally involved comparisons of standard and developmental items with regard to the relative effects of the items on the body movements of the wearer. The information from the research is used to guide design of military clothing and equipment to ensure that the items are compatible with the mobility requirements of the wearer while also fulfilling their intended functions.

The tests of gross motor performance differ somewhat in how they are carried out, but each yields a quantitative measure of the maximum extent of movement about joints of the body (Saul and Jaffe, 1955). The measurements are made mainly with gravity goniometers (Laubach, 1978; Leighton, 1942). The tests have proven to be reliable, sensitive to clothing and equipment manipulations, and unaffected by practice (Dusek and Teichner, 1956; Saul and Jaffe, 1955). They are also easy to administer and to score.

Although there are positive features associated with these traditional tests of motor performance, the measurement techniques employed do have limitations. For example, the extent of movement about body joints cannot be measured for complex, continuous motions, such as walking and running. Video-based, computer-controlled systems are now available that can be used to analyze videotaped images of continuous movements in a variety of ways.

The video-based motion analysis systems provide the capability for a more complete, quantitative rendering of a greater variety of human movements than is possible using the traditional measurement techniques. Thus, these systems have the potential for expanding the types of information that can be acquired to guide design of military clothing and equipment. Furthermore, extensive, quantitative descriptions of soldiers'

movements under various clothing and equipment conditions are becoming increasingly important as inputs into ever more sophisticated and widely used computer models employed by military organizations to simulate the battlefield maneuvers of individual soldiers and units of soldiers. For these reasons, video-based techniques are now being applied in this laboratory to analyze soldiers' movements as affected by clothing and equipment items. The findings from the first study in which a motion analysis system was used in this laboratory are presented here and in two other reports (Woods, Polcyn, O'Hearn, Rosenstein, and Bensel, 1997a, 1997b).

Analysis of Walking Gait

This first study was designed to address some issues associated with the introduction of the video-based measurement techniques. This report contains findings from a video-based analysis of walking gait. A number of temporal and kinematic variables were analyzed to compare gait patterns and body postures of soldiers wearing a regular duty uniform alone and in combination with an armor vest and a fighting load.

Previous research studies examining the effects of load-carrying gear on body movements during walking have, in the main, focused on such independent variables as backpack designs and pack load weights (Kinoshita, 1985; Martin and Nelson, 1982, 1986; Martin, Nelson, and Shin, 1982, 1983; Pierrynowski, Norman, and Winter, 1981). It has been found that the relative duration of the swing phase of the gait cycle (i.e., one foot off the ground) decreases with increases in pack load weight, whereas the relative duration of the double support phase (i.e., both feet on the ground) increases (Kinoshita, 1985). Forward inclination of the trunk also increases with increasing backpack loads (Martin and Nelson, 1982, 1986), as does the extent of knee flexion upon contact of the foot with the ground (Kinoshita, 1985).

Angular velocities of joint movement may be affected by the load carried. Hamill and Bensel (1996a, 1996b) acquired kinematic data on men and women walking at an externally paced 1.15 m/s (4.1 km/hr). Both the men and the women were tested without load-carrying equipment and while carrying a fighting load of 9.1 kg along with a backpack load of 13.6 kg. The men were also tested with the 9.1-kg fighting load plus a backpack load of 19.3 kg. For both genders, maximum hip and knee flexion velocities increased significantly with load. For the men, but not the women, maximum ankle dorsiflexion and plantarflexion velocities also increased as load was increased.

A backpack was not included in the present study; the fighting load that was used consisted of a web belt and suspenders with ammunition pouches, a canteen, and an entrenching tool attached to the belt and positioned on the front and sides of the wearer's body. The weight of the fighting gear with all components was 7.8 kg. In research conducted by Martin and Nelson (1982, 1986) and sponsored by this laboratory, a fighting load of the same design and weight as that used in the present study was included

among the test conditions. The study by Martin and Nelson included analysis of the gait of men and women walking at an externally controlled velocity of 1.78 m/s (6.4 km/hr) while wearing the fighting gear over a regular duty uniform. Under this condition, the total weight of all items worn or carried on the body, including clothing, was approximately 9.4 kg. In another condition, a helmet, an armor vest, and an M-16 rifle were added, bringing the total weight on the body to approximately 17.5 kg. Data were also collected under a baseline condition consisting of only a T-shirt and shorts, with a weight of less than 1.0 kg.

Martin and Nelson (1982, 1986) found that the number of steps completed per second, with a step being defined as the point from heel strike of one foot to the point of heel strike of the other foot, was significantly greater under the heaviest weight condition than it was under the two other conditions. The heaviest weight was also associated with the shortest stride length. In addition, the duration of the swing phase was significantly shorter under the heaviest weight condition. The only postural variable analyzed by Martin and Nelson was trunk angle. It was not significantly affected by weight condition.

Purposes of the Study

One of the issues addressed in this study was how body range of motion data acquired using video-based techniques compared with data acquired using the traditional measurement methods of gravity goniometers and meter sticks. The study was also an investigation of the effects that armor vests and load-carrying equipment have on soldiers' movements. Seven planar movements were studied using both the traditional and the video-based techniques, and walking gait was analyzed using the video-based techniques. Results of the comparison of the traditional and the video-based measurement techniques are presented in Woods et al. (1997a). Another report (Woods et al., 1997b) contains findings from the video-based analysis of the effects of the armor vests and load-carrying equipment on the planar movements.

The portion of the study reported here was exploratory in nature. It was carried out primarily to assess the extent to which gait-related dependent measures may be sensitive to changes in the encumbrances imposed on the body by armor vests and fighting loads. For this reason, a large number of temporal and kinematic gait variables were calculated and analyzed. Soldiers were tested in regular duty uniforms only, with the weight of all items worn being less than 2 kg, and with the addition of an armor vest and a fighting load, with the weight of all items worn or carried being approximately 14 kg. Bensel et al. (1980) found that, compared with the duty uniform, use of an armor vest and a fighting load reduced maximum range of motion on simple planar movements. In this study, the contrast between the two conditions was extended to the more complex and continuous movement of walking.

The conditions tested in this study were not identical in terms of weights or clothing and equipment worn to those studied by Martin and Nelson (1982, 1986). However, like the work of Martin and Nelson, the present study included analysis of gait patterns under conditions in which a backpack load was not carried. Martin and Nelson analyzed only one angular orientation of the body, trunk angle. In the present study, a more extensive list of kinematic variables was examined, along with a number of temporal variables. The kinematic measures calculated and analyzed included not only linear and angular displacements of body landmarks and segments, but linear and angular velocities and accelerations. Hamill and Bensel (1996a, 1996b) found angular velocities of some body segments to increase with increasing load. The present study provided the opportunity to explore the effects on linear and angular velocities and accelerations of lighter loads than those used by Hamill and Bensel.

Method

Participants

The participants were 12 male soldiers from the Enlisted Volunteer Platoon at the U.S. Army Soldier Systems Command, Natick, Massachusetts. They were fully informed about the purposes and risks of the study and gave their written consent to participate in accordance with Army Regulation 70-25. The participants' demographic information is summarized in Table 1.

Table 1
Participants' Characteristics (N = 12)

Statistic	Stature (cm)	Crotch Ht. (cm)	Chest Circum. (cm)	Waist Circum. (cm)	Age (yrs.)
M	178.12	82.85	100.08	87.48	20.70
SD	6.55	3.17	6.93	7.62	1.54

Clothing and Equipment Conditions

In the course of the entire study, participants were tested under 18 clothing and equipment conditions. Walking gait was analyzed for two of these. In both conditions, the coat and trousers of the standard-issue Temperate Battledress Uniform (BDU) were worn along with standard-issue, leather combat boots. The second condition also included an armor vest and load-carrying equipment. The armor vest was the Army's standard-issue, fragmentation protective vest that is part of the Personnel Armor System for Ground Troops (PASGT). The load-carrying equipment was the Army's standard-issue fighting load that is part of the All-Purpose Lightweight Individual Carrying Equipment (ALICE) system. The armor vest and the load-carrying gear are described in Appendix A. For the uniform only condition, the total weight of all items worn on the body was approximately 1.7 kg. When the armor vest and fighting load were also used, the total weight of all items worn or carried was approximately 13.5 kg.

Apparatus

An SVHS shuttered camcorder (Panasonic model AG450), which ran at 60 Hz, was used to videotape the participants as they walked. At the beginning of a test session, the camera was checked with a circular bubble level to ensure that it was level in the fore-aft and the lateral directions. A meter stick was also videotaped for use in establishing a scale factor during the tape digitizing process.

After the test sessions, the videotapes were encoded and digitized using specialized computer hardware and software (Peak Performance Technologies, Inc.), a color video monitor (Sony Trinitron model PVM-1341), and an SVHS video cassette recorder (Panasonic model AG7300). The digitizing was done manually by a trained anthropometrist. It consisted of marking previously established anatomical landmarks in each frame of videotape. The landmarks digitized are identified below in the Procedure section. The digitized data were smoothed using a fourth order, zero lag Butterworth digital filter.

Procedure

Before testing began, the participants were fitted for the clothing and equipment and familiarized with the movements to be performed. Each man then participated in six experimental sessions, either in the morning or in the afternoon of six days. The sessions for a participant were scheduled for the same time each day. A session lasted approximately 2.25 hr and involved testing three of the 18 clothing and equipment conditions that comprised the study. Each participant was exposed to the clothing and equipment conditions in a different random order. Ambient temperature in the test area was maintained at 19.4 °C.

For each condition, the participant performed two successive trials on all the planar movements and on the walking task while either the traditional or the video-based measurement methods were used. Then, he repeated this process while the other measurement method was used. The participant spent approximately 5 min completing a questionnaire regarding the extent to which the clothing and equipment being worn may have hindered his performance. A 10-min rest followed during which any armor or load-carrying gear was removed. Testing resumed with the next condition and continued until three conditions were completed. For half the participants, testing of the conditions was always conducted using the traditional techniques first, followed by the video-based techniques; for the remaining participants, the video-based techniques were used first.

For the gait task, the participant was instructed to take five strides forward along a horizontal surface at a natural cadence. Walking velocity was not externally controlled and participants were not instructed to attempt to maintain the same velocity from trial to trial. This task was performed twice in succession for each measurement technique.

Only the video-based data are presented in this report. The participant was videotaped with the camera to his right at 90° to the plane in which he was walking (i.e., a sagittal view).

The videotapes of the walking task were encoded and digitized at a later date. The digitizing was done using the specialized hardware and software of the motion analysis system (Peak Performance Technologies, Inc.). The middle (i.e., third) gait cycle was digitized and analyzed. A stride cycle was defined as the time between successive contacts of the right heel with the ground. Digitizing consisted of a trained anthropometrist marking the anatomical landmarks in each video frame. Landmarks visually obstructed by clothing or opposing limbs, or that were internal, were approximated using anatomical and visual cues as to their position. The landmarks are indicated pictorially in Figure 1. They were:

Most superior point on head
Most posterior point on head
Menton, bottom of the chin
Glabella, anterior point on the frontal bone midway between the brow ridges
Right tragion, superior point on the juncture of the cartilaginous flap of the right ear with the head
Right infraorbitale, lowest point on the anterior border of the bony socket of the right eye
Right shoulder, at the center of the right humeral head
Right elbow, at the lateral epicondyle of the right distal humerus
Right wrist, at the center of the right radiocarpal joint
Right hip, at the center of the right femoral head
Right knee, at the lateral epicondyle of the right distal femur
Right ankle, at the right lateral malleolus
Right heel, at the most posterior and inferior point of the right foot
Right toe, at the most anterior and inferior point of the right foot
Left hip, at the center of the left femoral head
Left knee, at the lateral epicondyle of the left distal femur
Left ankle, at the left lateral malleolus
Left heel, at the most posterior and inferior point of the left foot
Left toe, at the most anterior and inferior point of the left foot

Dependent Variables

Seventy-nine dependent measures were extracted from the digitized gait data. The stride cycle was divided into a series of overlapping phases that were determined by important events in the cycle and the dependent variables were calculated with respect to these phases. The phases, which are presented pictorially in Figure 2, were as follows:

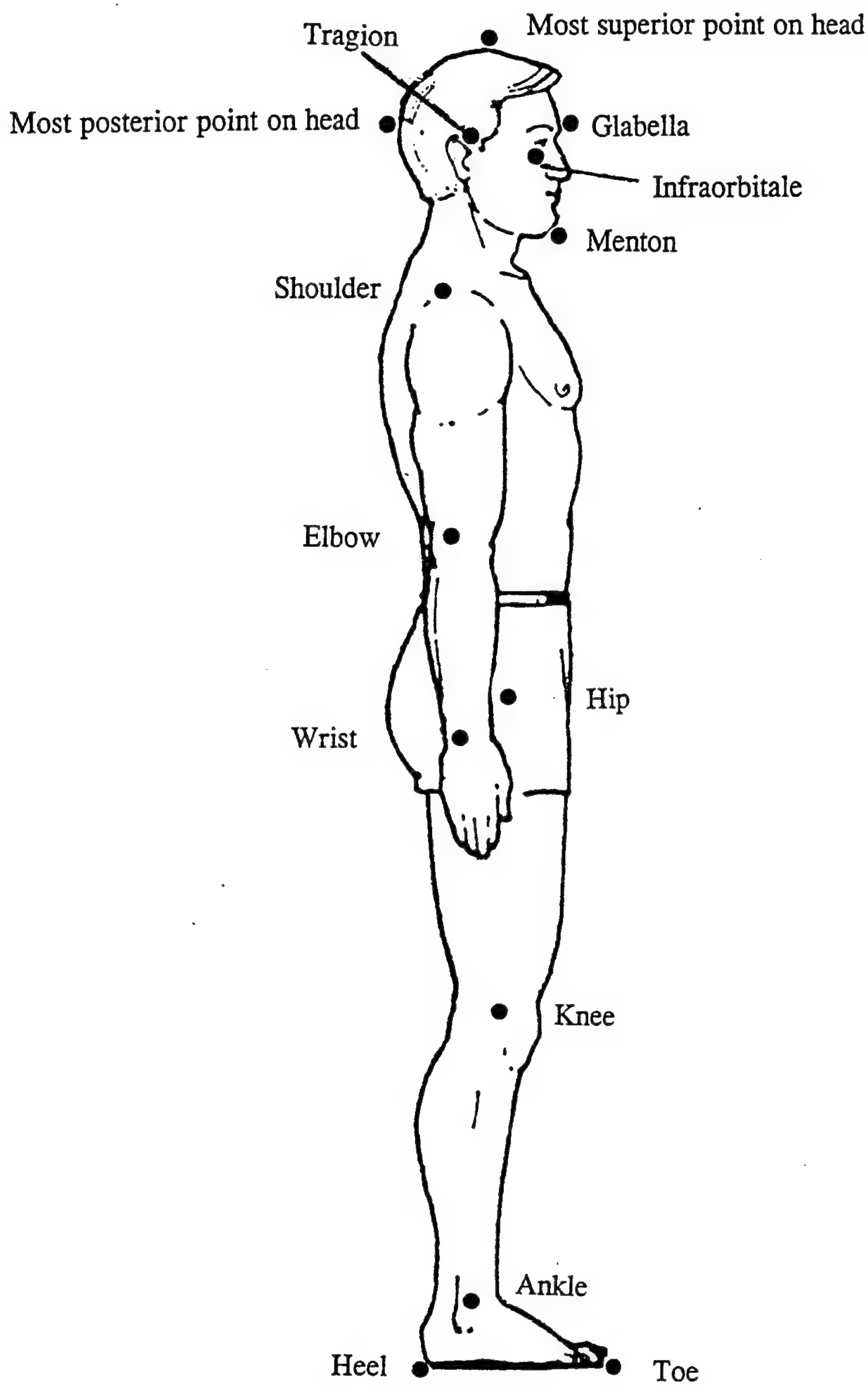

Figure 1. Body landmarks digitized.

Phase I: Time of right heel strike 1 to time of right toe off
Phase II: Time of right toe off to time of right heel strike 2
Phase III: Time of maximum right hip extension to time of maximum right hip flexion
Phase IV: Time of left heel strike to time of right heel strike 2
Phase IVa: Time of left heel strike to time when right knee joint changes from flexion to extension
Phase IVb: Time when right knee joint changes from flexion to extension to time of right heel strike 2
Phase V: Time of right heel strike 1 to time of left heel strike
Phase VI: Time of right toe strike to time of right heel off
Phase VII: Time of right heel strike 1 to time of right toe strike

The variables calculated included ranges of linear displacements of body points and of joint angles, linear and angular velocities and accelerations of various body segments, and temporal gait parameters. The variables are fully described in Appendix B.

The body segment angles examined included the head, the trunk, the hip joint, the knee joint, and the ankle joint. Definitions of the angles are as follows:

Head Angle

The head was considered to be in a standard position (i.e., the Frankfort plane) when a segment connecting the right tragion and the right infraorbitale points was horizontal. The angle between the horizontal and the segment was calculated as a measure of head motion. The infraorbitale point was the vertex of the angle. Positive values of the angle are associated with a forward tilt of the head, that is, movement of the chin toward the chest. Negative values indicate a backward tilt, or movement of the chin away from the chest.

Trunk Angle

This angle indicates the extent of forward inclination or tilt of the trunk. The angle measured was that between the horizontal and a segment connecting the right tragion and the right hip points, with the hip point as the vertex. Lower values of the angle indicate a greater forward inclination of the trunk.

Hip Angle

This was defined as the angle between the horizontal and a segment connecting the right hip and the right knee points, with the hip point being the vertex. Positive values indicate hip extension and negative values indicate hip flexion.

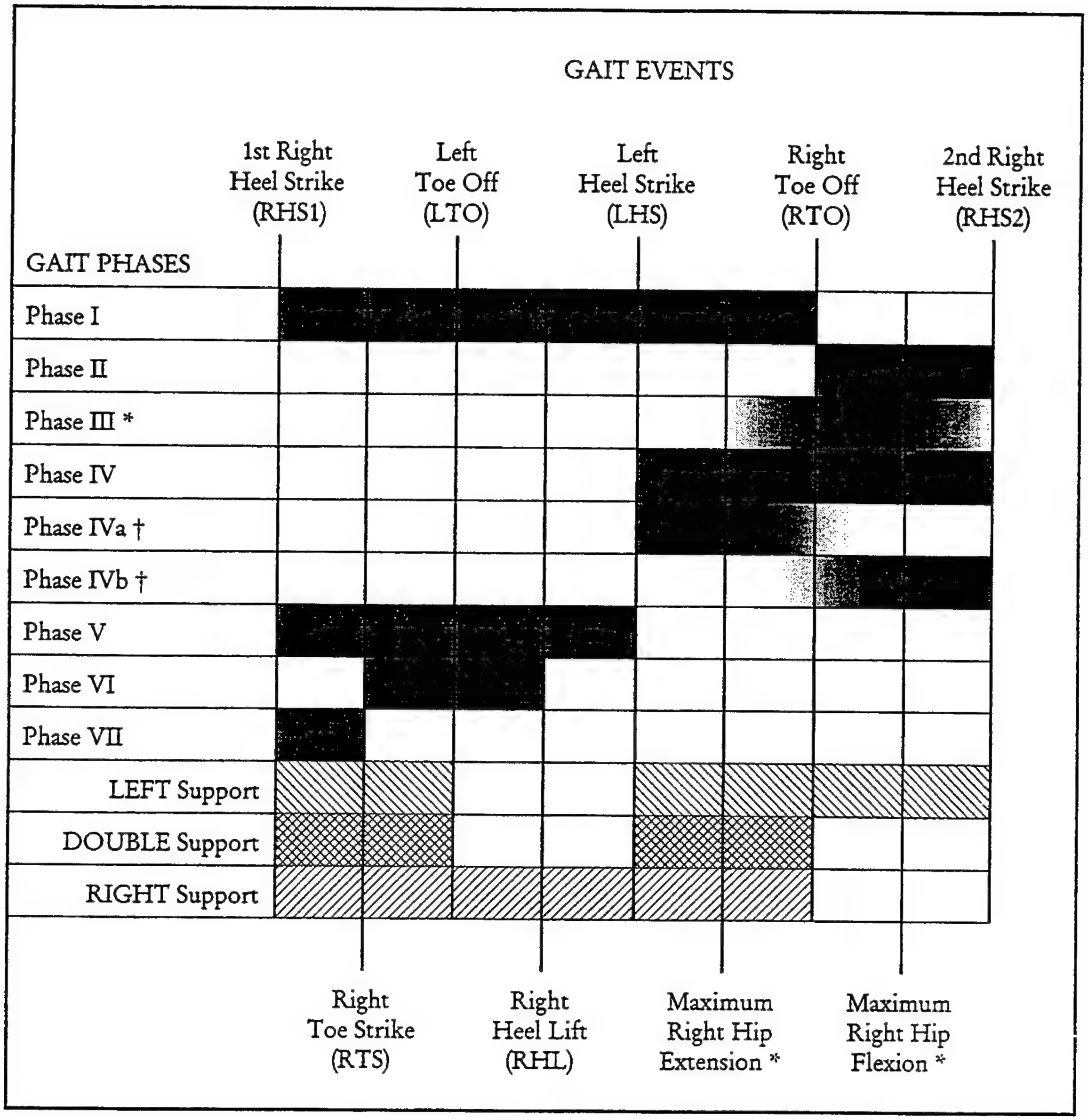

Figure 2. Gait cycle schematic indicating gait phases as defined by gait events. The durations of the phases are not to scale. Shading gradients indicate variability of phase endpoints with respect to gait events. *The times of maximum right hip extension and flexion are theoretically at or just prior to RTO and RHS, respectively. Thus, Phases II and III are frequently coterminous. †Phases IVa and IVb divide Phase IV at the moment when the right knee joint changes from flexion to extension. This event occurs near RTO.

Knee Angle

This was defined as the angle formed by a segment connecting the right hip and knee points and a second segment connecting the right knee and ankle points, with the knee as the vertex. Positive values indicate knee flexion and negative, knee extension.

Ankle Angle

This was the angle formed by a segment connecting the right knee and the ankle points and a second segment connecting the right ankle and the heel points, with the ankle as the vertex. Positive values correspond to dorsiflexion and negative to plantarflexion.

Statistical Analyses

Each of the 79 dependent variables was analyzed separately. All analyses were carried out on a personal computer using SPSS/PC+, version 3.1. Analyses of variance (ANOVAs) were performed to contrast the temporal and kinematic variables describing walking gait when the uniform was worn alone with walking gait when the armor vest and the fighting load were also used. Differences between the two consecutive trials under each clothing and equipment condition were also examined. The ANOVAs were for repeated measures on two factors: Clothing and Equipment Condition (uniform, uniform + armor vest + fighting load) and Trials (1, 2).

The significance level for each analysis was set at $p < .05$. Given the large number of analyses carried out, the likelihood of a Type I error was high. However, because this work was exploratory in nature, the determination was made not to test for significance at a more stringent level. In those instances in which a main effect was found to be significant, Tukey's Honestly Significant Difference (*HSD*) procedure was applied as a post hoc test, with the significance level again set at $p < .05$.

Results and Discussion

The results of the ANOVAs performed on the dependent measures are summarized in Table 2. Only two of the 79 analyses yielded a significant interaction. This paucity of interaction effects is not unexpected given that the two walking trials were performed in succession and no clothing or equipment items were removed or adjusted between trials. A significant main effect of clothing and equipment was obtained in six of the analyses and a significant main effect of trial in four analyses. Table 3 lists the means for each level of the two independent variables. Asterisks are used in the table to indicate the dependent measures that were significantly affected by the clothing and equipment or the trial variables. The findings pertaining to the independent variables are discussed below.

Clothing and Equipment Effects

The clothing and equipment worn had a significant effect ($p < .05$) on two temporal measures: left support period (Stride7) and double support period (Stride9), both of which are expressed as a percentage of stride period (Table 2). The percentage of the gait cycle spent in left support and the percentage of the cycle spent in double support both increased with the addition of the armor vest and the fighting load (Table 3). However, the percentage of the stride period spent in right support (Stride8) was not significantly affected by the clothing and equipment variable (Table 3). This apparent asymmetry may be due in part to the events used to define the gait cycle. Right heel strike defined the beginning and the end of the cycle. Thus, left support time was comprised of two separate segments of the cycle. The result may have been minor differences in total times computed for the right and the left support periods. Some evidence for this lies in the fact that relative left support period was somewhat shorter than right support period when the uniform was worn alone as well as when it was worn with the addition of the armor vest and the fighting load.

The clothing and equipment variable did not have a significant effect ($p > .05$) on stride length (Stride1) or stride period (Stride2). Therefore, the changes in the left support and the double support percentage values correspond to increases in the actual times spent in left support and in double support, respectively.

Kinoshita (1985) also found an increase in the percentage of the gait cycle spent in double support as the load being carried on the body increased. In Kinoshita's study, the walking velocity was externally controlled at 1.2 m/s (4.5 km/hr). Kinoshita theorized that a significant difference in the double support period would not be obtained if walking velocity were chosen freely by each participant. In the present study, walking velocity was chosen by the participant, yet the relative double support period increased when an armor vest and fighting load were added to the items being worn.

Table 2
Summary of ANOVAs for the Gait Variables

Variable	Clothing and Equipment Main Effect		Trial Main Effect		Interaction	
	MS_C / MS_{Error}	F	MS_T / MS_{Error}	F	MS_{CxT} / MS_{Error}	F
Stride Measures						
Stride1	93.46 / 54.42	1.72	5.47 / 9.84	<1.00	5.48 / 14.30	<1.00
Stride2	212.52 / 3986.34	<1.00	6650.52 / 579.79	11.47**	196.02 / 1982.75	<1.00
Stride3	0.01 / 0.01	1.29	0.01 / 0.00	31.34***	0.00 / 0.00	<1.00
Stride4	6.75 / 2.75	2.45	0.33 / 1.15	<1.00	2.08 / 1.72	1.21
Stride5	0.75 / 3.30	<1.00	0.33 / 2.06	<1.00	14.08 / 1.17	11.99**
Stride6	0.75 / 3.75	<1.00	3.00 / 0.91	3.30	0.00 / 1.73	<1.00
Stride7	14.08 / 2.72	5.18*	2.08 / 2.27	<1.00	5.33 / 2.88	1.85
Stride8	1.02 / 2.93	<1.00	4.69 / 0.69	6.82*	0.02 / 1.20	<1.00
Stride9	24.08 / 4.99	4.82*	12.00 / 3.36	3.57	6.75 / 6.39	1.06
Head Measures						
Tragion	0.00 / 0.00	3.58	0.00 / 0.00	6.50*	0.00 / 0.00	1.20
Headtilt	35.36 / 9.93	3.56	7.04 / 12.80	<1.00	5.98 / 9.27	<1.00

Table 2 *(continued)*

Variable	Clothing and Equipment Main Effect		Trial Main Effect		Interaction	
	MS_C / MS_{Error}	F	MS_T / MS_{Error}	F	MS_{CxT} / MS_{Error}	F
Wrist Measures						
Wrist1	0.01 / 0.00	4.17	0.01 / 0.00	2.40	0.00 / 0.00	1.72
Wrist2	0.02 / 0.03	<1.00	0.00 / 0.02	<1.00	0.03 / 0.02	1.50
Trunk Measures						
Trunk1	3.89 / 2.50	1.56	0.27 / 1.62	<1.00	0.06 / 1.76	<1.00
Trunk2	0.01 / 0.78	<1.00	0.02 / 0.31	<1.00	0.20 / 0.41	<1.00
Trunk3	1.66 / 2.89	<1.00	1.10 / 3.43	<1.00	0.97 / 1.86	<1.00
Trunk4	10.67 / 0.85	12.48**	0.21 / 0.62	<1.00	0.39 / 0.56	<1.00
Hip Measures — Vertical Displacement						
Hip1	0.00 / 0.00	5.21*	0.00 / 0.00	1.80	0.00 / 0.00	<1.00
Hip2	0.00 / 0.00	<1.00	0.00 / 0.00	1.37	0.00 / 0.00	<1.00
Hip3	0.00 / 0.00	7.86*	0.00 / 0.00	<1.00	0.00 / 0.00	<1.00
Hip Measures — Angular Range						
Hip4	3.28 / 6.74	<1.00	0.09 / 3.61	<1.00	3.63 / 1.81	2.01
Hip5	23.16 / 14.82	1.56	4.37 / 2.07	2.11	0.02 / 3.61	<1.00
Hip6	23.16 /14.82	1.56	4.37 / 2.07	2.11	0.02 / 3.61	<1.00

Table 2 *(continued)*

Variable	Clothing and Equipment Main Effect MS_C / MS_{Error}	Clothing and Equipment Main Effect F	Trial Main Effect MS_T / MS_{Error}	Trial Main Effect F	Interaction MS_{CxT} / MS_{Error}	Interaction F
Hip Measures — Minimum and Maximum Angular Velocity and Acceleration						
Hip7	371.30 / 1015.66	<1.00	928.40 / 451.30	2.06	196.43 / 304.15	<1.00
Hip8	162.07 / 207.62	<1.00	38.52 / 101.92	<1.00	172.52 / 201.70	<1.00
Hip9	61061.33/ 89188.24	<1.00	108870.75 / 37712.57	2.89	494.08 / 51699.45	<1.00
Hip10	94430.02 / 111472.20	<1.00	1419.19 / 99726.01	<1.00	31878.52 / 100895.98	<1.00
Hip11	1192.01 / 633.30	1.88	452.64 / 562.77	<1.00	14.08 / 409.98	<1.00
Hip12	3.00 / 523.39	<1.00	343.47 / 253.46	1.36	6.45 / 165.11	<1.00
Hip13	137388.88 / 139294.82	<1.00	210145.33 / 131415.33	1.60	5461.33 / 117923.15	<1.00
Hip14	17214.19 / 90571.10	<1.00	25162.52 / 108265.16	<1.00	46438.52 / 58414.43	<1.00
Hip15	1192.01 / 633.30	1.88	452.64 / 562.77	<1.00	14.08 / 409.98	<1.00
Hip16	51.46 / 432.42	<1.00	37.99 / 150.89	<1.00	94.36 / 273.96	<1.00
Hip17	27122.52 / 312483.02	<1.00	10950.52 / 125979.48	<1.00	212.52 / 168934.38	<1.00

Table 2 *(continued)*

Variable	Clothing and Equipment Main Effect		Trial Main Effect		Interaction	
	MS_C / MS_{Error}	F	MS_T / MS_{Error}	F	MS_{CxT} / MS_{Error}	F
Hip18	15877.69 / 90910.23	<1.00	23541.02 / 109163.66	<1.00	44226.02 / 58192.13	<1.00
Hip19	0.00 / 0.02	<1.00	0.01 / 0.00	2.87	0.00 / 0.01	<1.00
Knee Measures — Angular Range						
Knee1	3.72 / 29.59	<1.00	3.98 / 6.58	<1.00	21.17 / 2.62	8.07*
Knee2	3.39 / 10.73	<1.00	7.58 / 3.58	2.12	28.89 / 6.34	4.55
Knee3	3.39 / 10.73	<1.00	7.58 / 3.58	2.12	28.89 / 6.34	4.55
Knee Measures — Minimum and Maximum Linear and Angular Velocity and Acceleration						
Knee4	0.00 / 0.01	<1.00	0.00 / 0.01	<1.00	0.00 / 0.00	<1.00
Knee5	0.08 / 0.05	1.55	0.00 / 0.02	<1.00	0.02 / 0.02	1.19
Knee6	0.01 / 0.15	<1.00	0.26 / 0.19	1.32	0.08 / 0.19	<1.00
Knee7	0.00 / 2.73	<1.00	4.08 / 5.83	<1.00	0.52 / 2.88	<1.00
Knee8	0.05 / 0.02	3.34	0.02 / 0.01	2.90	0.00 / 0.01	<1.00
Knee9	0.07 / 0.05	1.45	0.00 / 0.02	<1.00	0.03 / 0.02	1.33
Knee10	0.11 / 0.89	<1.00	3.80 / 1.62	2.35	2.48 / 0.63	3.92
Knee11	1.27 / 2.38	<1.00	0.91 / 4.51	<1.00	5.20 / 1.98	2.62

Table 2 *(continued)*

Variable	Clothing and Equipment Main Effect		Trial Main Effect		Interaction	
	MS_C / MS_{Error}	F	MS_T / MS_{Error}	F	MS_{CxT} / MS_{Error}	F
Knee12	4682.72 / 1652.48	2.83	155.16 / 424.53	<1.00	314.67 / 929.62	<1.00
Knee13	764.80 / 2050.08	<1.00	3.20 / 851.10	<1.00	56.33 / 402.36	<1.00
Knee14	17941.33 / 317550.61	<1.00	239701.33 / 862948.97	<1.00	5334.08 / 77635.72	<1.00
Knee15	36190.08 / 1206336.00	<1.00	289230.75 / 509111.57	<1.00	36300.00 / 754402.00	<1.00
Knee16	0.23 / 0.02	10.68**	0.01 / 0.04	<1.00	0.07 / 0.03	1.98
Knee17	0.07 / 0.05	1.45	0.00 / 0.02	<1.00	0.03 / 0.02	1.33
Knee18	1.92 / 1.57	1.23	6.75 / 2.58	2.61	2.25 / 1.16	1.94
Knee19	0.96 / 2.56	<1.00	3.63 / 5.99	<1.00	4.56 / 1.57	2.92
Knee20	645.33 / 971.43	<1.00	1361.07 / 719.37	1.89	221.02 / 657.64	<1.00
Knee21	764.80 / 2050.08	<1.00	3.20 / 851.10	<1.00	56.33 / 400.04	<1.00
Knee22	1740.02 / 431780.93	<1.00	184636.02 / 596443.02	<1.00	244102.69 / 166616.87	1.47
Knee23	44957.52 / 400645.48	<1.00	173881.69 / 119028.19	1.46	76081.69 / 82969.10	<1.00

Table 2 *(continued)*

Variable	Clothing and Equipment Main Effect		Trial Main Effect		Interaction	
	MS_C / MS_{Error}	F	MS_T / MS_{Error}	F	MS_{CxT} / MS_{Error}	F
Knee24	0.01 / 0.01	<1.00	0.01 / 0.01	1.27	0.00 / 0.01	<1.00
Knee25	0.02 / 0.04	<1.00	0.05 / 0.01	3.42	0.00 / 0.02	<1.00
Knee26	0.71 / 1.64	<1.00	2.00 / 1.84	1.09	2.61 / 0.82	3.19
Knee27	0.54 / 3.60	<1.00	0.08 / 2.71	<1.00	0.42 / 3.23	<1.00
Knee28	4682.72 / 1652.48	2.83	155.16 / 424.53	<1.00	314.67 / 929.62	<1.00
Knee29	30.40 / 1259.88	<1.00	667.52 / 1009.64	<1.00	50.02 / 1379.02	<1.00
Knee30	33708.00 / 248916.50	<1.00	62785.33 / 984082.92	<1.00	49408.33 / 217677.29	<1.00
Knee31	50570.08 / 1137029.40	<1.00	270600.33 / 517348.06	<1.00	29900.08 / 784054.63	<1.00
			Knee Measures — Temporal Measure			
Knee32	0.00 / 0.00	<1.00	0.00 / 0.00	1.01	0.00 / 0.00	<1.00
			Ankle Measures			
Ankle1	7.66 / 12.19	<1.00	0.72 / 10.19	<1.00	3.54 / 16.24	<1.00
Ankle2	110.23 / 27.41	4.02	29.36 / 12.27	2.39	1.00 / 14.27	<1.00

Table 2 *(continued)*

Variable	Clothing and Equipment Main Effect		Trial Main Effect		Interaction	
	MS_C / MS_{Error}	F	MS_T / MS_{Error}	F	MS_{CxT} / MS_{Error}	F
			Heel and Toe Measures			
Heel	0.00 / 0.01	<1.00	0.00 / 0.00	<1.00	0.00 / 0.00	1.38
Toe1	0.01 / 0.02	<1.00	0.06 / 0.02	2.72	0.03 / 0.02	1.56
Toe2	0.07 / 0.06	1.26	0.02 / 0.02	<1.00	0.03 / 0.05	<1.00
Toe3	0.19 / 4.37	<1.00	2.25 / 5.59	<1.00	4.69 / 5.33	<1.00
Toe4	22.55 / 30.29	<1.00	35.88 / 19.30	1.86	43.13 / 25.22	1.71
Toe5	0.01 / 0.01	<1.00	0.00 / 0.01	<1.00	0.01 / 0.01	2.09
Toe6	0.01 / 0.01	<1.00	0.00 / 0.01	<1.00	0.00 / 0.01	<1.00
Toe7	0.04 / 3.12	<1.00	0.85 / 4.27	<1.00	15.41 / 3.33	4.63
Toe8	0.50 / 39.37	<1.00	0.00 / 25.39	<1.00	1.88 / 12.11	<1.00

Note. For both main effects and the interaction, df = 1, 11.
$*p < .05$. $**p < .01$. $***p < .001$.

Table 3
Means (and Standard Deviations) of the Gait Variables for Each Clothing and Equipment Condition and Trial (*N* = 12)

	Clothing and Equipment		Trial	
Variable	Uniform	Uniform + Armor Vest + Fighting Load	1	2
		Stride Measures		
Stride1 (cm)	140.21 (11.52)	137.42 (10.20)	138.48 (9.49)	139.15 (11.16)
Stride2 (ms)	1252.79 (112.48)	1257.00 (130.34)	1266.67 (116.32)	1243.12** (122.09)
Stride3 (m/s)	1.13 (0.14)	1.10 (0.14)	1.10 (0.13)	1.13*** (0.14)
Stride4 (%)	23.79 (1.50)	24.54 (1.48)	24.25 (1.39)	24.08 (1.31)
Stride5 (%)	55.04 (1.34)	54.79 (1.56)	54.83 (1.51)	55.00 (1.15)
Stride6 (%)	74.00 (2.11)	74.25 (1.21)	74.38 (1.28)	73.88 (1.69)
Stride7 (%)	68.88 (0.93)	69.96* (2.09)	69.62 (1.60)	69.21 (1.57)
Stride8 (%)	68.67 (2.18)	68.96 (1.14)	69.12 (1.46)	68.50* (1.67)
Stride9 (%)	37.29 (3.16)	38.71* (2.88)	38.50 (2.89)	37.50 (3.02)
		Head Measures		
Tragion (%)	3.40 (0.49)	3.67 (0.64)	3.61 (0.56)	3.46* (0.49)
Headtilt (deg)	7.49 (1.56)	9.21 (3.38)	7.97 (2.22)	8.73 (3.22)

Table 3 *(continued)*

Variable	Clothing and Equipment: Uniform	Clothing and Equipment: Uniform + Armor Vest + Fighting Load	Trial: 1	Trial: 2
		Wrist Measures		
Wrist1 (0-1)	0.70 (0.03)	0.68 (0.06)	0.68 (0.06)	0.70 (0.04)
Wrist2 (s)	0.14 (0.06)	0.10 (0.17)	0.11 (0.16)	0.12 (0.07)
		Trunk Measures		
Trunk1 (deg)	85.71 (2.00)	85.14 (2.51)	85.50 (2.19)	85.35 (2.38)
Trunk2 (deg)	2.54 (0.84)	2.57 (0.75)	2.57 (0.54)	2.54 (0.86)
Trunk3 (deg)	82.81 (2.42)	82.44 (2.91)	82.78 (2.59)	82.47 (2.76)
Trunk4 (deg)	5.42 (0.80)	4.48** (0.78)	4.88 (0.87)	5.02 (0.61)
		Hip Measures — Vertical Displacement		
Hip1 (%)	3.04 (0.89)	3.42* (0.51)	3.08 (0.63)	3.38 (0.88)
Hip2 (%)	2.71 (0.58)	2.71 (0.45)	2.63 (0.43)	2.79 (0.50)
Hip3 (%)	2.38 (0.64)	3.00* (0.77)	2.63 (0.77)	2.75 (0.62)
		Hip Measures — Angular Range		
Hip4 (deg)	39.64 (3.46)	39.11 (3.67)	39.42 (3.20)	39.33 (3.70)
Hip5 (deg)	24.86 (4.32)	23.47 (4.11)	23.86 (3.40)	24.46 (4.21)
Hip6 (deg)	24.86 (4.32)	23.47 (4.11)	23.86 (3.40)	24.46 (4.21)

Table 3 *(continued)*

Variable	Clothing and Equipment: Uniform	Clothing and Equipment: Uniform + Armor Vest + Fighting Load	Trial: 1	Trial: 2
Hip Measures — Minimum and Maximum Angular Velocity and Acceleration				
Hip7 (deg/s)	-174.95 (30.25)	-169.39 (19.53)	-176.57 (25.50)	-167.78 (19.08)
Hip8 (deg/s)	94.20 (15.09)	97.88 (15.33)	96.94 (13.96)	95.15 (14.66)
Hip9 (deg/s^2)	-1678.17 (278.23)	-1749.50 (165.87)	-1666.21 (209.07)	-1761.46 (188.35)
Hip10 (deg/s^2)	962.83 (243.50)	1051.54 (259.74)	1012.62 (278.27)	1001.75 (208.44)
Hip11 (deg/s)	-169.60 (37.28)	-159.64 (19.34)	-167.69 (35.52)	-161.55 (21.59)
Hip12 (deg/s)	31.38 (22.18)	31.88 (23.10)	28.96 (17.30)	34.31 (24.34)
Hip13 (deg/s^2)	-654.25 (160.16)	-761.25 (355.48)	-641.58 (206.33)	-773.92 (324.81)
Hip14 (deg/s^2)	1462. 38 (280.19)	1500.25 (299.00)	1458.52 (335.54)	1504.21 (253.30)
Hip15 (deg/s)	-169.60 (37.28)	-159.64 (19.34)	-167.69 (35.52)	-161.55 (21.59)
Hip16 (deg/s)	1.40 (12.22)	3.47 (11.35)	1.54 (7.57)	3.32 (8.94)
Hip17 (deg/s^2)	-420.79 (262.50)	-468.33 (351.69)	-429.46 (155.32)	-459.67 (274.25)
Hip18 (deg/s^2)	1462.38 (280.19)	1498.75 (299.71)	1458.42 (335.54)	1502.71 (254.70)
Hip19 (%)	89.33 (11.94)	90.98 (10.27)	91.63 (9.37)	88.68 (8.40)

Table 3 *(continued)*

Variable	Clothing and Equipment: Uniform	Clothing and Equipment: Uniform + Armor Vest + Fighting Load	Trial: 1	Trial: 2
Knee Measures — Angular Range				
Knee1 (deg)	59.89 (4.63)	60.45 (3.55)	60.46 (3.05)	59.88 (3.64)
Knee2 (deg)	65.94 (4.32)	65.40 (2.65)	66.07 (3.23)	65.27 (3.42)
Knee3 (deg)	65.94 (4.32)	65.40 (2.65)	66.07 (3.23)	65.27 (3.42)
Knee Measures — Minimum and Maximum Linear and Angular Velocity and Acceleration				
Knee4 (m/s)	0.30 (0.09)	0.30 (0.08)	0.29 (0.10)	0.30 (0.07)
Knee5 (m/s)	2.55 (0.31)	2.47 (0.18)	2.51 (0.27)	2.51 (0.19)
Knee6 (m/s^2)	0.82 (0.25)	0.79 (0.30)	0.88 (0.32)	0.73 (0.27)
Knee7 (m/s^2)	12.54 (1.91)	12.55 (1.49)	12.25 (2.06)	12.84 (1.78)
Knee8 (m/s)	0.83 (0.13)	0.76 (0.13)	0.77 (0.12)	0.82 (0.12)
Knee9 (m/s)	2.55 (0.31)	2.47 (0.18)	2.51 (0.27)	2.51 (0.19)
Knee10 (deg/s)	1.94 (1.00)	2.04 (1.00)	2.27 (1.35)	1.71 (0.75)
Knee11 (deg/s)	13.25 (1.92)	12.92 (1.75)	12.95 (1.95)	13.22 (2.00)
Knee12 (m/s^2)	-380.57 (42.96)	-360.82 (36.74)	-368.90 (37.29)	-372.49 (34.52)
Knee13 (m/s^2)	329.83 (43.32)	321.85 (24.73)	325.58 (34.15)	326.10 (26.87)
Knee14 (deg/s^2)	-3794.96 (690.87)	-3833.12 (595.64)	-3884.46 (852.96)	-3743.12 (614.20)

Table 3 *(continued)*

Variable	Clothing and Equipment: Uniform	Clothing and Equipment: Uniform + Armor Vest + Fighting Load	Trial: 1	Trial: 2
Knee15 (deg/s^2)	4380.29 (926.21)	4435.21 (837.50)	4485.38 (641.70)	4330.12 (917.64)
Knee16 (m/s)	1.01 (0.22)	0.87** (0.24)	0.92 (0.21)	0.95 (0.27)
Knee17 (m/s)	2.55 (0.31)	2.47 (0.18)	2.51 (0.27)	2.51 (0.19)
Knee18 (deg/s)	3.74 (1.35)	3.34 (1.34)	3.92 (1.48)	3.17 (1.39)
Knee19 (deg/s)	12.88 (2.10)	12.59 (1.58)	12.46 (2.26)	13.01 (1.88)
Knee20 (m/s^2)	-4.44 (19.22)	2.90 (28.61)	-6.10 (25.84)	4.55 (19.86)
Knee21 (m/s^2)	329.83 (43.32)	321.85 (24.73)	325.58 (34.15)	326.10 (26.87)
Knee22 (deg/s^2)	-3687.58 (744.38)	-3699.62 (615.95)	-3755.62 (832.42)	-3631.58 (568.25)
Knee23 (deg/s^2)	2249.21 (503.01)	2310.42 (344.62)	2219.62 (241.64)	2340.00 (415.43)
Knee24 (m/s)	0.87 (0.12)	0.85 (0.12)	0.84 (0.12)	0.84 (0.10)
Knee25 (m/s)	1.94 (0.23)	1.98 (0.29)	1.93 (0.27)	1.99 (0.24)
Knee26 (deg/s)	2.07 (1.18)	2.31 (0.95)	2.40 (1.37)	1.99 (0.72)
Knee27 (deg/s)	10.97 (2.13)	11.18 (2.40)	11.12 (2.47)	11.03 (1.93)
Knee28 (m/s^2)	-380.57 (42.96)	-360.82 (36.74)	-368.90 (37.29)	-372.49 (34.51)

Table 3 *(continued)*

Variable	Clothing and Equipment: Uniform	Clothing and Equipment: Uniform + Armor Vest + Fighting Load	Trial: 1	Trial: 2
Knee29 (m/s^2)	46.01 (33.75)	44.42 (29.16)	48.94 (30.24)	41.48 (30.83)
Knee30 (deg/s^2)	-3459.42 (535.82)	-3512.42 (625.21)	-3522.08 (775.46)	-3449.75 (666.51)
Knee31 (deg/s^2)	4370.29 (944.64)	4435.21 (837.50)	4477.83 (659.86)	4327.67 (921.14)
Knee Measures — Temporal Measure				
Knee32 (0-1)	0.48 (0.04)	0.48 (0.04)	0.49 (0.04)	0.48 (0.04)
Ankle Measures				
Ankle1 (deg)	12.88 (4.73)	13.68 (4.18)	13.40 (4.91)	13.16 (3.84)
Ankle2 (deg)	15.07 (5.99)	17.68 (5.41)	15.80 (4.56)	16.95 (5.70)
Heel and Toe Measures				
Heel (s)	-0.05 (0.08)	-0.04 (0.08)	-0.04 (0.07)	-0.05 (0.06)
Toe1 (m/s)	1.12 (0.10)	1.09 (0.16)	1.07 (0.15)	1.14 (0.13)
Toe2 (m/s)	4.63 (0.37)	4.56 (0.41)	4.58 (0.41)	4.61 (0.34)
Toe3 (m/s^2)	6.42 (1.80)	6.30 (2.11)	6.58 (1.66)	6.14 (2.35)
Toe4 (m/s^2)	35.40 (5.56)	36.77 (6.60)	35.22 (5.03)	36.95 (6.61)

Table 3 *(continued)*

Variable	Clothing and Equipment: Uniform	Clothing and Equipment: Uniform + Armor Vest + Fighting Load	Trial: 1	Trial: 2
Toe5 (m/s)	0.18 (0.05)	0.21 (0.08)	0.19 (0.05)	0.02 (0.08)
Toe6 (m/s)	1.19 (0.14)	1.16 (0.10)	1.18 (0.12)	1.17 (0.11)
Toe7 (m/s^2)	4.63 (1.78)	4.69 (1.53)	4.80 (1.90)	4.53 (1.57)
Toe8 (m/s^2)	13.66 (5.00)	13.45 (4.07)	13.55 (4.07)	13.56 (4.25)

Note. Asterisks indicate Clothing and Equipment and Trial main effects found to be significant in the ANOVAs.
$^*p < .05$. $^{**}p < .01$. $^{***}p < .001$.

There are several possible reasons for the increase in the percentage of the gait cycle spent in double support. One possibility is that increasing the load being carried on the body increases the difficulty of maintaining balance. Because the double support period is the portion of the gait cycle when the body has the largest base of support, it is arguably the most stable portion. Thus, when bearing heavier loads, individuals may adjust their gait patterns to maintain balance by increasing double support time. Another possible explanation relates to momentum during walking. If additional load weight decreases forward momentum being carried on from the previous step, it will take additional time for force to be developed by the trailing leg, generating enough forward momentum to propel the body into the next step. Other explanations for the increase in double support time are also possible. More insight into this issue could be gained through use of electromyography to measure lower limb muscle activity and a force plate to measure ground reaction forces during walking.

With regard to the kinematic measures, minimum trunk tilt angles in Phase II (Trunk1), the period from RTO to RHS2, and in Phase V (Trunk3), the period from RHS1 to LHS, did not differ significantly ($p < .05$) as a function of the clothing and equipment variable (Table 2). In analyzing the effects of conditions that included an armor vest and a fighting load, but not a backpack, Martin and Nelson (1982, 1986) also

did not find significant changes in the forward inclination of the trunk with changes in the weight of the load being worn on the body.

Another trunk angle variable analyzed in the present study, but not in Martin and Nelson's (1982, 1986) work, was significantly affected ($p < .05$) by the clothing and equipment variable. This was the range of trunk tilt angle during Phase V of the gait cycle (Trunk2), which extended from RHS1 to LHS (Table 2). The range decreased with the addition of the armor vest and fighting load (Table 3). This effect is probably due to the stiffness of the vest. Woods et al. (1997b) found that the armor vest significantly restricted bending at the waist. The vest may also inhibit bending at the spine.

It is likely that the decrease in trunk flexion range influences other aspects of the gait pattern. For example, a decrease in the normal swinging of the trunk during gait could decrease the amount of forward momentum that is carried from one step to the next. This would require actively generating additional momentum to maintain walking speed, thereby increasing fatigue. In addition, balance is maintained during normal gait because the different segments of the body interact in fairly precise ways to maintain the necessary relationship between the instantaneous center of mass and the base of support. Changing the range of motion of one body segment necessitates compensatory changes in the movement patterns of the other body segments, possibly resulting in a less efficient gait cycle.

Two measures of the vertical movement of the right hip, expressed as a percentage of stride length, were significantly affected ($p < .05$) by the clothing and equipment variable (Table 2). One was the relative range of vertical displacement of the right hip in Phase I of the gait cycle (Hip1), which extended from RHS1 to RTO. The other was the same measurement made during Phase III (Hip3), which was the period from maximum right hip extension to maximum right hip flexion. On both measures, the range of vertical hip movement increased with the addition of the armor vest and fighting load (Table 3). One possible reason for these findings is that the increased load increases the natural "list" or downward tilt of the pelvis during walking. Limitations in the data make it impossible to explore other explanations. For example, it cannot be ascertained from the available data whether this movement was symmetric, that is, whether the range of movement of the left hip was also increased. It is also not known whether the increase in movement was due to rotation of the pelvis or increased vertical movement of the pelvis as a unit, which would probably imply an increase in vertical displacement of the center of mass. This latter option would likely result in increased energy expenditure during gait because increased vertical movement of the center of mass requires that more work be done to move the center of mass against gravity. Use of two or more cameras to capture the walking movement and subsequent three-dimensional analysis of the gait pattern would contribute to understanding the hip displacement findings.

With regard to the knee movement measures, the heavier load on the body, represented by the armor vest and the fighting load, did not increase the extent of knee

flexion as Kinoshita (1985) found. However, clothing and equipment did significantly ($p < .05$) affect linear velocity of the knee, a variable that was not investigated by Kinoshita (Table 2). The minimum linear velocity of the right knee in Phase IVa (Knee16), the phase that extended from LHS to the right knee flexion/extension transition point, was lower when the armor vest and the fighting load were used than when the uniform was worn alone (Table 3). The decreased linear velocity may be related to the fact that the duration of the double support period was longer when the vest and fighting load were worn, but no causal relationship can be determined. It is possible that the increased load limits the speed with which the knee can move at the beginning of Phase IVa, with a resultant increase in double support time. Conversely, it is possible that the carrying of a heavier load of itself increases double support time, with the velocity of the knee during Phase IVa being lower as a result.

With the exception of this knee velocity variable (Knee16), the dependent measures significantly affected by clothing and equipment condition are unrelated to an individual's body dimensions or walking velocity. The left support (Stride7) and the double support periods (Stride9) are measured in seconds, and then normalized by the stride period. Therefore, they are not affected by an individual's natural walking velocity. Trunk tilt (Trunk2) is measured in degrees and the size of the angle does not depend on the length of the segments making up the angle. The measures of hip vertical displacement (Hip1 and Hip3) are measured in meters, but normalized by stride length. Thus, they are not affected by a person's stature or leg length.

Aside from the measure of minimum linear velocity of the right knee (Knee16), the clothing and equipment variable did not have a significant effect on dependent measures involving linear and angular velocities and accelerations of points on the body or body segments. Hamill and Bensel (1996a, 1996b) found that maximum hip and knee flexion velocities increased with load, but their study participants carried fighting and backpack loads totalling over 21 kg, whereas the heavier of the two clothing and equipment conditions in the present study was less than 14 kg, inclusive of everything worn and carried on the body.

Trial Effects

The stride lengths (Stride1) of the participants were slightly longer in the second of the two successive walking trials, but there was no significant difference ($p > .05$) between the trials (Tables 2 and 3). However, stride period (Stride2) and stride velocity (Stride3) did reveal a significant trial effect ($p < .05$); stride period was shorter and velocity higher in the second trial (Table 3). After completing the second gait trial, participants either responded to a questionnaire and had a rest break or began to perform a series of planar movement that were measured using traditional methods, rather than the video-based techniques. Thus, the second trial marked the completion of

a testing segment for the participants, and it is possible that the faster pace on the trial reflected an "end spurt" in anticipation of moving on to the next test activity.

Another stride variable, right support period as a percentage of stride period (Stride8), was also significantly affected ($p < .05$) by the trial variable (Table 2). The relative right support period, as a percentage of stride period, was shorter in the second than in the first trial (Table 3). However, the trial variable did not have a significant effect on left support period as a percentage of stride period (Stride7; Tables 2 and 3). There is, therefore, an apparent asymmetry, similar to that found in the analysis of the clothing and equipment variable. Again, this asymmetry may be due to the manner in which the gait cycle was defined, resulting in minor differences in times calculated for the right and the left support periods.

Trial had a significant effect ($p < .05$) on one kinematic variable. This was the range of vertical displacement of the right tragion in Phase I (RHS1-RTO) as a percentage of stride length (Tragion). There was a smaller range of vertical displacement on the second than on the first trial (Table 3). It is possible that the finding is associated with the decreased stride period (Stride2) and increased stride velocity (Stride3) in the second trial. A similar measure was made at the right hip. It was the range of vertical displacement of the right hip point in Phase I as a percentage of stride length (Hip1). The difference between trials was not significant ($p > .05$) on this measure (Table 2).

Conclusions

In the uniform only condition, study participants wore items weighing approximately 1.7 kg. The addition of the armor vest and the fighting load represented a weight increase of 11.8 kg. Thus, the total weight of all items worn or carried under this condition was quite low. In addition, the increased load was distributed on the torso, as opposed to the full weight being carried in a backpack. Despite these factors, however, the values of a number of gait parameters differed significantly depending upon whether or not the armor vest and the fighting load were worn. Therefore, the video-based gait analysis techniques employed in this study promise to be useful in assessing the effects of clothing and equipment on locomotion, even when the body is not encumbered by heavy loads.

The dependent measures significantly affected by the clothing and equipment variable included both temporal and kinematic measures of gait. It was found that, compared with the uniform alone, use of the armor vest and the fighting load was associated with an increase in the left support and the double support periods, a decrease in the range of trunk tilt angle, and an increase in the range of vertical displacement of the right hip. At least some of these changes associated with wearing the vest and load-carrying equipment may result in a less efficient gait pattern, which could lead to earlier onset of physical fatigue during overground walking or marching and, possibly, to injury.

A large number of kinematic variables were calculated and analyzed in this exploratory study. Among them were linear and angular velocities and accelerations of points on the body or body segments. Only one of these measures differentiated between the two clothing and equipment conditions. Therefore, linear and angular velocities and accelerations do not seem to be affected when loads on the body are relatively light and walking velocity is chosen by the test participant. Additional testing would be required to establish whether or not the velocity and acceleration parameters are sensitive to the clothing and equipment conditions included in this study when walking velocity is constant from trial to trial and externally paced.

The results of this study suggest improvements for future biomechanical studies of the effects on gait of various designs of armor vests and fighting loads. In particular, capturing the movement with two or more cameras and carrying out a three-dimensional analysis of gait patterns would provide a more complete understanding of the interaction between the wearer and the clothing and equipment. Augmenting the kinematic data by capturing ground reaction force-time histories and muscle activity of the lower limbs would also be beneficial, as these other techniques may reveal differences between different armor vest or fighting load designs that the kinematic data do not. Another factor to consider in establishing testing protocols for future studies of armor vest or fighting load designs is that, after a prolonged period of walking while wearing these items, individuals may become fatigued and gait patterns may change over time as a

result. There is the possibility that gait patterns change in a different manner depending upon vest or fighting load design features. There is also the possibility that design differences between such items influence gait patterns only after a period of walking. Thus, future studies should address the effects on gait of wearing the items for varying amounts of time.

References

Bensel, C. K., Bryan, L. P., and Mellian, S. A. (1977). *The psychomotor performance of women in cold weather clothing* (Tech. Rep. NATICK/TR-77/031). Natick, MA: U.S. Army Natick Research and Development Command.

Bensel, C. K., Fink, D. S., and Mellian, S. A. (1980). *The psychomotor performance of men and women wearing two types of body armor* (Tech. Rep. NATICK/TR-80/014). Natick, MA: U.S. Army Natick Research and Development Command.

Bensel, C. K., and Lockhart, J. M. (1975). *The effects of body armor and load-carrying equipment on psychomotor performance* (Tech. Rep. 75-92-CEMEL). Natick, MA: U.S. Army Natick Development Center.

Bensel, C. K., Teixeira, R. A., and Kaplan, D. B. (1987). *The effects of U.S. Army chemical protective clothing on speech intelligibility, visual field, body mobility and psychomotor coordination of men* (Tech. Rep. NATICK/TR-87/037). Natick, MA: U.S. Army Natick Research, Development and Engineering Center.

Dusek, E. R. (1958a). *Encumbrance of arctic clothing* (Tech. Rep. EP-85). Natick, MA: U.S. Army Quartermaster Research and Engineering Center.

Dusek, E. R. (1958b). *Standardization of tests of gross motor performance* (Tech. Rep. EP-81). Natick, MA: U.S. Army Quartermaster Research and Engineering Center.

Dusek, E. R., and Teichner, W. H. (1956). *The reliability and intercorrelations of eight tests of body flexion* (Tech. Rep. EP-31). Natick, MA: U.S. Army Quartermaster Research and Development Center.

Hamill, J., and Bensel, C. K. (1996a). *Biomechanical analysis of military boots. Phase II, Volume I: Human user testing of military and commercial footwear* (Tech. Rep. NATICK/TR-96/011). Natick, MA: U.S. Army Natick Research, Development and Engineering Center.

Hamill, J., and Bensel, C. K. (1996b). *Biomechanical analysis of military boots. Phase II, Volume II: Human user testing of military and commercial footwear* (Tech. Rep. NATICK/TR-96/012). Natick, MA: U.S. Army Natick Research, Development and Engineering Center.

Kinoshita, H. (1985). Effects of different loads and carrying systems on selected biomechanical parameters describing walking gait. *Ergonomics, 28,* 1347-1362.

Laubach, L. (1978). Range of joint motion. In Staff of Anthropology Research Project, Webb Associates (Eds.), *Anthropometric source book. Volume I: Anthropometry for designers* (NASA Reference Publication 1024) (Chapter VI). Houston, TX: National Aeronautics and Space Administration, Lyndon B. Johnson Space Center.

Leighton, T. R. (1942). A simple objective and reliable measure of flexibility. *Research Quarterly, 13,* 205-216.

Lockhart, J. M., and Bensel, C. K. (1977). *The effects of layers and type of liner on the psychomotor performance of men* (Tech. Rep. NATICK/TR-77/018). Natick, MA: U.S. Army Natick Research and Development Command.

Martin, P. E., and Nelson, R. C. (1982). *Volume III. Effects of gender, load, and backpack on the temporal and kinematic characteristics of walking gait* (Tech. Rep. NATICK/TR-82/021). Natick, MA: U.S. Army Natick Research and Development Laboratories.

Martin, P. E., and Nelson, R. C. (1986). The effect of carried loads on the walking patterns of men and women. *Ergonomics, 29,* 1191-1202.

Martin, P. E., Nelson, R. C., and Shin, In-Sik. (1982). *Effects of gender, frame length, and participation time on load carrying behavior* (Tech. Rep. NATICK/TR-82/041). Natick, MA: U.S. Army Natick Research and Development Laboratories.

Martin, P. E., Nelson, R. C., and Shin, In-Sik. (1983). *Effects of backpack frame length, pack load, and participation time on the physical performance of men and women* (Tech. Rep. NATICK/TR-83/043). Natick, MA: U.S. Army Natick Research and Development Center.

McGinnis, J. M. (1972). *Some effects of body armor on motor performance* (Tech. Rep. 73-13-PR). Natick, MA: U.S. Army Natick Laboratories.

Pierrynowski, M. R., Norman, R. W., and Winter, D. A. (1981). Mechanical energy analyses of the human during load carriage on a treadmill. *Ergonomics, 24,* 1-14.

Saul, E. V., and Jaffe, J. (1955). *The effects of clothing on gross motor performance* (Tech. Rep. EP-12). Natick, MA: U.S. Army Quartermaster Research and Development Center.

Woods, R. J., Polcyn, A. F., O'Hearn, B. E., Rosenstein, R. A., and Bensel, C. K. (1997a). *Analysis of the effects of body armor and load-carrying equipment on soldiers' movements. Part I: Technique comparisons* (Tech. Rep. NATICK/TR-97/002). Natick, MA: U.S. Army Natick Research, Development and Engineering Center.

Woods, R. J., Polcyn, A. F., O'Hearn, B. E., Rosenstein, R. A., and Bensel, C. K. (1997b). *Analysis of the effects of body armor and load-carrying equipment on soldiers' movements. Part II: Armor vest and load-carrying equipment assessment* (Tech. Rep. NATICK/TR-97/003). Natick, MA: U.S. Army Natick Research, Development and Engineering Center.

APPENDIX A

DESCRIPTIONS OF ARMOR VEST AND LOAD-CARRYING EQUIPMENT

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Fragmentation Protective Vest, Personnel Armor System for Ground Troops (PASGT Vest)

The standard-issue, PASGT vest is made of 13 plies of ballistic filler. The filler is water-repellent treated Kevlar with a weight of 474.8 g/m^2. The inner and the outer shells are water-repellent treated ballistic nylon with a weight of 271.3 g/m^2. The layer that makes up the inner cover of the vest is olive green. The outer cover is in camouflage colors and design. The ballistic filler in the back of the vest is divided into four sections. The three, upper sections slide over each other and the lower section during body movement. The closure, which runs the length of the front of the vest, is formed with hook and pile fastener tape. The side overlaps are made flexible through the use of sewn-in, elastic webbing that is 3.8 cm wide. The vest also has a fragmentation protective, 3/4 stand-up collar, articulating shoulder pads with elastic webbing and snaps, two front pockets, and rifle butt patches at the shoulders. The ballistic materials in the PASGT vest provide protection from fragmenting munitions. In a size medium, this vest weighs 4.0 kg.

Fighting Load, All-Purpose Lightweight Individual Carrying Equipment (ALICE Gear)

This standard-issue, load-carrying gear includes an equipment belt that is worn around the waist and suspenders that cross over the shoulders and attach to the front and the back of the belt. Components of the fighting load are attached to the belt. These include two ammunition cases, an entrenching tool with a carrier, and a 1-quart canteen with a cover. Each ammunition case has two external pockets for fragmentation grenades. For this study, the canteen was filled with water and each ammunition case was loaded with weights totalling 1.6 kg to simulate the weight and the bulk of three, 30-round magazines of M16 ammunition. One of the two grenade pockets on each ammunition case was filled with weights totalling 0.5 kg, the weight of a fragmentation grenade. The total weight of the ALICE fighting load was 7.8 kg.

APPENDIX B

DESCRIPTIONS OF DEPENDENT VARIABLES

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Stride Measures

Stride1 (cm): Stride length, measured as the horizontal distance between the right heel at RHS1 and the right heel at RHS2.

Stride2 (ms): Stride period, the time between RHS1 and RHS2.

Stride3 (m/s): Stride velocity, calculated by dividing stride length by stride period.

Stride4 (%): Percent of stride period at which LTO occurs.

Stride5 (%): Percent of stride period at which LHS occurs.

Stride6 (%): Percent of stride period at which RTO occurs.

Stride7 (%): Left support period as a percentage of stride period.

Stride8 (%): Right support period as a percentage of stride period.

Stride9 (%): Double support period as a percentage of stride period.

Head Measures

Tragion (%): Range of vertical displacement of the right tragion in Phase I (RHS1-RTO) as a percentage of stride length.

Headtilt (deg): Range of head tilt angle (Frankfort plane) in Phase I (RHS1-RTO).

Wrist Measures

Wrist1 (a dimensionless unit between 0 and 1): Fractional portion of Phase I (RHS1-RTO) completed when the right arm ceases forward swing. This was taken as the first within-phase frame where the horizontal speed of the right wrist point divided by the horizontal speed of the right hip point changes from ≥ 1 to < 1.

Wrist2 (s): Time difference obtained by subtracting the instant of maximum acceleration of the right knee from the instant when the right arm, represented by the right wrist point, ceases or minimizes forward swing.

Trunk Measures

Trunk1 (deg): Minimum trunk tilt angle in Phase II (RTO-RHS2).

Trunk2 (deg): Range of trunk tilt angle in Phase II (RTO-RHS2).

Trunk3 (deg): Minimum trunk tilt angle in Phase V (RHS1-LHS).

Trunk4 (deg): Range of trunk tilt angle in Phase V (RHS1-LHS).

Hip Measures — Vertical Displacement

Hip1 (%): Range of vertical displacement of the right hip point in Phase I (RHS1-RTO) as a percentage of stride length.

Hip2 (%): Range of vertical displacement of the right hip point in Phase II (RTO-RHS2) as a percentage of stride length.

Hip3 (%): Range of vertical displacement of the right hip point in Phase III (period from maximum right hip extension to maximum right hip flexion) as a percentage of stride length.

Hip Measures — Angular Range

Hip4 (deg): Range of right hip joint angle in Phase I (RHS1-RTO).

Hip5 (deg): Range of right hip joint angle in Phase II (RTO-RHS2).

Hip6 (deg): Range of right hip joint angle in Phase III (period from maximum right hip extension to maximum right hip flexion).

Hip Measures — Minimum and Maximum Angular Velocity and Acceleration

Hip7 (deg/s): Minimum angular velocity of the right hip joint in Phase I (RHS1-RTO).

Hip8 (deg/s): Maximum angular velocity of the right hip joint in Phase I (RHS1-RTO).

Hip9 (deg/s^2): Minimum angular acceleration of the right hip joint in Phase I (RHS1-RTO).

Hip10 (deg/s^2): Maximum angular acceleration of the right hip joint in Phase I (RHS1-RTO).

Hip11 (deg/s): Minimum angular velocity of the right hip joint in Phase II (RTO-RHS2).

Hip12 (deg/s): Maximum angular velocity of the right hip joint in Phase II (RTO-RHS2).

Hip13 (deg/s^2): Minimum angular acceleration of the right hip joint in Phase II (RTO-RHS2).

Hip14 (deg/s^2): Maximum angular acceleration of the right hip joint in Phase II (RTO-RHS2).

Hip15 (deg/s): Minimum angular velocity of the right hip joint in Phase III (period from maximum right hip extension to maximum right hip flexion).

Hip16 (deg/s): Maximum angular velocity of the right hip joint in Phase III (period from maximum right hip extension to maximum right hip flexion).

Hip17 (deg/s^2): Minimum angular acceleration of the right hip joint in Phase III (period from maximum right hip extension to maximum right hip flexion).

Hip18 (deg/s^2): Maximum angular acceleration of the right hip joint in Phase III (period from maximum right hip extension to maximum right hip flexion).

Hip19 (%): Velocity of the right hip point at the time of maximum vertical displacement, expressed as a percentage of stride velocity.

Knee Measures — Angular Range

Knee1 (deg): Range of right knee joint angle in Phase I (RHS1-RTO).

Knee2 (deg): Range of right knee joint angle in Phase II (RTO-RHS2).

Knee3 (deg): Range of right knee joint angle in Phase IV (LHS-RHS2).

Knee Measures — Minimum and Maximum Linear and Angular Velocity and Acceleration

Knee4 (m/s): Minimum linear velocity of the right knee point in Phase I (RHS1-RTO).

Knee5 (m/s): Maximum linear velocity of the right knee point in Phase I (RHS1-RTO).

Knee6 (m/s^2): Minimum linear acceleration of the right knee point in Phase I (RHS1-RTO).

Knee7 (m/s^2): Maximum linear acceleration of the right knee point in Phase I (RHS1-RTO).

Knee8 (m/s): Minimum linear velocity of the right knee point in Phase IV (LHS-RHS2).

Knee9 (m/s): Maximum linear velocity of the right knee point in Phase IV (LHS-RHS2).

Knee10 (deg/s): Minimum angular velocity of the right knee joint in Phase IV (LHS-RHS2).

Knee11 (deg/s): Maximum angular velocity of the right knee joint in Phase IV (LHS-RHS2).

Knee12 (m/s^2): Minimum linear acceleration of the right knee point in Phase IV (LHS-RHS2).

Knee13 (m/s^2): Maximum linear acceleration of the right knee point in Phase IV (LHS-RHS2).

Knee14 (deg/s^2): Minimum angular acceleration of the right knee joint in Phase IV (LHS-RHS2).

Knee15 (deg/s^2): Maximum angular acceleration of the right knee joint in Phase IV (LHS-RHS2).

Knee16 (m/s): Minimum linear velocity of the right knee point in Phase IVa (LHS to right knee flexion/extension transition point).

Knee17 (m/s): Maximum linear velocity of the right knee point in Phase IVa (LHS to right knee flexion/extension transition point).

Knee18 (deg/s): Minimum angular velocity of the right knee joint in Phase IVa (LHS to right knee flexion/extension transition point).

Knee19 (deg/s): Maximum angular velocity of the right knee joint in Phase IVa (LHS to right knee flexion/extension transition point).

Knee20 (m/s^2): Minimum linear acceleration of the right knee point in Phase IVa (LHS to right knee flexion/extension transition point).

Knee21 (m/s^2): Maximum linear acceleration of the right knee point in Phase IVa (LHS to right knee flexion/extension transition point).

Knee22 (deg/s^2): Minimum angular acceleration of the right knee joint in Phase IVa (LHS to right knee flexion/extension transition point).

Knee23 (deg/s^2): Maximum angular acceleration of the right knee joint in Phase IVa (LHS to right knee flexion/extension transition point).

Knee24 (m/s): Minimum linear velocity of the right knee point in Phase IVb (Right knee flexion/extension transition point to RHS2).

Knee25 (m/s): Maximum linear velocity of the right knee point in Phase IVb (Right knee flexion/extension transition point to RHS2).

Knee26 (deg/s): Minimum angular velocity of the right knee joint in Phase IVb (Right knee flexion/extension transition point to RHS2).

Knee27 (deg/s): Maximum angular velocity of the right knee joint in Phase IVb (Right knee flexion/extension transition point to RHS2).

Knee28 (m/s^2): Minimum linear acceleration of the right knee point in Phase IVb (Right knee flexion/extension transition point to RHS2).

Knee29 (m/s^2): Maximum linear acceleration of the right knee point in Phase IVb (Right knee flexion/extension transition point to RHS2).

Knee30 (deg/s^2): Minimum angular acceleration of the right knee joint in Phase IVb (Right knee flexion/extension transition point to RHS2).

Knee31 (deg/s^2): Maximum angular acceleration of the right knee joint in Phase IVb (Right knee flexion/extension transition point to RHS2).

Knee Measures — Temporal Measure

Knee32 (a dimensionless unit between 0 and 1): Fractional portion of Phase IV (LHS-RHS2) completed when knee flexion/extension transition point occurs. This is calculated as the duration of Phase IVa divided by the duration of Phase IV.

Ankle Measures

Ankle1 (deg): Range of right ankle joint in Phase II (RTO-RHS2).

Ankle2 (deg): Range of right ankle joint in Phase VI (RTS-RHO).

Heel and Toe Measures

Heel (s): Time difference obtained by subtracting the time of RHO from the time of LHS. This may be a negative value.

Toe1 (m/s): Minimum linear velocity of the right toe in Phase II (RTO-RHS2).

Toe2 (m/s): Maximum linear velocity of the right toe in Phase II (RTO-RHS2).

Toe3 (m/s^2): Minimum linear acceleration of the right toe in Phase II (RTO-RHS2).

Toe4 (m/s^2): Maximum linear acceleration of the right toe in Phase II (RTO-RHS2).

Toe5 (m/s): Minimum linear velocity of the right toe in Phase VII (RHS1-RTS)

Toe6 (m/s): Maximum linear velocity of the right toe in Phase VII (RHS1-RTS).

Toe7 (m/s^2): Minimum linear acceleration of the right toe in Phase VII (RHS1-RTS).

Toe8 (m/s^2): Maximum linear acceleration of the right toe in Phase VII (RHS1-RTS).